

Superbradyons and some possible dark matter signatures

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Superluminal preons (superbradyons) with a critical speed in vacuum much larger than the speed of light would, if they exist, play a fundamental role as constituents of the physical vacuum and of the conventional particles considered in standard theories. Then, standard Lorentz symmetry and quantum mechanics would not be ultimate fundamental properties of space-time and matter. If superbradyons are present as free particles in our Universe, they are expected to couple very weakly to "ordinary" matter, but they can spontaneously decay by emitting standard particles until they reach a speed equal or close to that of light. They would then form a cosmological sea where the relation between inertial and gravitational masses are expected to differ from conventional Physics. Superbradyons may be at the origin of cosmological and astrophysical phenomena usually associated to dark matter, dark energy and inflation. They can also be a source of conventional cosmic rays of all energies. In such a scenario, superbradyon spontaneous decays and similar interactions would be candidates to explain data on electron and positron abundances (PAMELA, ATIC, Fermi LAT, HESS, PPB-BETS) considered as possible dark matter signatures. Superbradyons emitting this radiation may even have comparatively small inertial masses, and kinetic energies not far away from those of the decay events. But in most cases, such "light" superbradyons could not be found at accelerator experiments. We comment on several basic physics and phenomenological issues in connection with the superbradyon hypothesis.

1. Introduction

Lorentz symmetry violation (LSV) at the Planck scale [1,2] is currently being tested by ultra-high energy cosmic-ray (UHECR) experiments [3,4,5]. Data from the AUGER [6] and HiRes [7] collaborations possibly confirm the existence of the Greisen-Zatsepin-Kuzmin (GZK) cutoff [8,9]. But in any case, several important LSV patterns and domains of parameters will remain allowed by these data [2].

Furthermore, the AUGER Collaboration has recently reported [10] a systematic inconsistency of available hadronic interaction models when attempting to simultaneously describe the observations of the X_{max} parameter and the number N_μ of produced muons. Data on X_{max} suggests UHECR masses to lie in the range between proton and iron, while N_μ data hint to heavier nuclei.

As explained in our previous papers [1,2], the composition of the UHECR spectrum is a crucial issue. The experimental confirmation of the GZK cutoff would lead to significant bounds on LSV, but it would not by itself allow to exclude

all possible LSV patterns and values of parameters. This is in particular the case for ultra-high energy (UHE) nuclei in the main Weak Doubly Special Relativity (WDSR, [1,2,12]) models.

In the family of models we suggested in 1997 [12] using quadratically deformed relativistic kinematics (QDRK), UHECR masses heavier typically than ≈ 30 times the proton mass would make compatible the observed flux suppression above $\approx 3 \cdot 10^{19}$ eV with a Lorentz symmetry violation of order ≈ 1 at the Planck scale for nucleons. If the UHECR masses are heavier than ≈ 10 times the proton mass, a LSV parameter ≈ 1 at the Planck scale can still be allowed for quarks and gluons.

The question of possible LSV does not only concern the kinematical and dynamical properties of standard particles, but also the very structure of matter at a deeper scale. At the Planck scale or at some other fundamental scale, the nature itself of elementary particles can drastically change. This may have important cosmological at inflation temperatures, as well as for dark matter and dark energy.

Implications of recent experimental results for the superbradyon hypothesis [11,12] have also been considered in our recent papers [1,2]. No data allow to exclude the existence of such particles. Superbradyons would have a critical speed in vacuum c_s much larger than the speed of light c , possibly corresponding to a superluminal Lorentz invariance. They may be the ultimate constituents of matter, and even obey a new mechanics as suggested below.

Standard preon models [13] assumed that preons feel the same Minkowskian space-time as quarks, leptons and gauge bosons, but there is no fundamental reason for this assumption. Preons were also assumed to carry the same kind of charges and quantum numbers as standard particles, but this is not necessarily the case if the gauge bosons are composite.

Superbradyons do not follow the standard preonic pattern. They can obey a new Lorentz symmetry with their own critical speed in vacuum replacing the speed of light in the metrics, and not be directly coupled to standard electroweak and strong interactions. They may manifest themselves through Planck-scale phenomena not ruled out by present experimental data, or more directly through their presence in matter (including vacuum) and in the Universe producing observable effects.

Superbradyonic remnants of earlier cosmological eras can possibly exist nowadays as free particles, and be very difficult to detect if they are not directly coupled to standard interactions. Contrary to tachyons, they would have positive mass and energy, violate standard special relativity and spontaneously emit radiation in vacuum in the form of conventional particles. They may be sources of UHECR and of large-scale phenomena in our Universe. As a final result of "Cherenkov" decays, a cosmological sea of superbradyons with speeds $\simeq c$ may have been formed.

Being the ultimate constituents of standard particles, superbradyons are expected to be also the constituents of the physical vacuum. They would play a fundamental dynamical and cosmological role, and could even lead to models of standard particle interactions without free Higgs-like bosons, somehow similar to the way the Cooper

condensate generates the effective photon mass in superconductivity.

Conventional particles can be the equivalent of phonons or solitons, as excitations of the superbradyonic ground state of matter (the vacuum) at the fundamental length scale. Their properties would then not be the ultimate fundamental properties of matter. Standard interactions may have been topologically generated in such a scenario. Also, our Universe may not be the only possible one. If different universes can also be formed, the properties of standard particles may be universe dependent.

The aim of this note is to briefly discuss possible explanations of the electron and positron abundances reported by PAMELA [14], ATIC [15], Fermi LAT [16], HESS [17] and PPB-BETS [18], in terms of superbradyonic physics.

As present data do not clearly fit any specific dark matter model, it seems legitimate to explore unconventional scenarios related to all possible kinds of new physics. In the case of cosmic superbradyons, radiation effects at all energies seem *a priori* easier to observe than possible interactions with detectors. Furthermore, assuming that superbradyons are the exotic source of the observed high-energy electrons and positrons, this would not by itself imply that they are (most of) the gravitational dark matter.

2. Possible effects of cosmic superbradyons

We assume the existence in our Universe of an absolute local rest frame (the vacuum rest frame, VRF), together with a fundamental length scale a where new physics is expected to appear [12]. A simple choice, but not compelling, would be to identify a with the Planck scale.

In our 1995 papers, the VRF was defined as the inertial frame where standard Lorentz symmetry for "ordinary" particles and the new space-time symmetry for the superluminal sector of matter were both exact symmetries up to very high-energy corrections due to the mixing between the two sectors. Actually, possible interactions between the superluminal particles and the physical vacuum of our Universe (similar, for instance, to refraction) should also be considered in such a

description. In particular, superbradyons would interact with vacuum inhomogeneities.

The vacuum rest frame is expected to be close to that where the cosmic microwave background radiation appears to be isotropic. The additivity of energy and momentum for standard particles is assumed to be preserved in all inertial frames. Standard Lorentz transformations can then be used, leading to frame-dependent versions of the deformed relativistic kinematics and, possibly, to singularities in the UHE region [12,19,20].

In what follows, all calculations are performed in the VRF.

It must be noticed that, although our LSV models [11,12] have been presented with simple phenomenological formulae, their theoretical formulation is much more general. The approximations made are a consequence of the energy domain considered, where energies are small as compared to Planck energy or to any other fundamental energy scale. Linearly deformed relativistic kinematics (LDRK,[12]) appears to be excluded by data, although hybrid models presenting a transition in the energy dependence of the deformation at very high energy can also be considered [20].

For simplicity, we also assume that, if superbradyons exist as free particles (cosmological remnants) or quasiparticles with our physical vacuum, their critical speed does not fundamentally differ from the value it may have in the absence of this vacuum or with another vacuum. Similarly, we consider here a situation with only one superluminal sector of matter and one superluminal critical speed, but our papers have also envisaged more general scenarios [12]. The question of whether other universes can exist with different physical vacua is an important one, but the subject will not be addressed here.

Energy and momentum conservation is assumed in any case to be valid at the energy and momentum scales considered here, as a simple consequence of space-time translation invariance. The situation can be more involved at a fundamental energy scale associated to a or to the Planck length.

Furthermore, energy and momentum conservation in all frames is a basic operating postu-

late of the patterns considered in [11,12] where energy and momentum are taken to be additive for pairs of free particles, and standard Lorentz transformations lead to a frame-dependent kinematics and standard Lorentz symmetry is preserved in the VRF. Possible deviations from this hypothesis will be briefly discussed below.

2.1. Superbradyons as sources of "ordinary" particles

The superbradyons considered here as possible electron and positron sources are assumed to have comparative low kinetic energies. Superbradyons with kinetic energies closer to Planck scale will in principle be able to release more energetic cosmic rays (including the UHECR region [11,12]).

In the VRF of our Universe, assuming globally a superluminal Lorentz invariance from superbradyonic physics with $c_s \gg c$ as the critical speed, the energy E and momentum p of a free superbradyon with critical speed in vacuum c_s , inertial mass m and speed v would be :

$$E = c (p^2 + m^2 c_s^2)^{1/2} \quad (1)$$

$$p = m v (1 - v^2 c_s^{-2})^{-1/2} \quad (2)$$

For $v \ll c_s$, these equations become :

$$E \simeq m c_s^2 + m v^2/2 \quad (3)$$

$$p \simeq m v \quad (4)$$

The kinetic energy E_{kin} being in this case :

$$E_{kin} \simeq m v^2/2 \quad (5)$$

In particular, $E_{kin} \gg p c$ for $v \gg c$. Superbradyons with $v > c$ are kinematically allowed to decay by emitting standard particles, although the lifetimes for such processes can be very long because of the weak couplings expected. These decays may still exist in the present Universe and play a cosmological role.

For v high enough, a superbradyon would be able to decay by emitting a set of conventional particles with total momentum $p_T \ll E_T c^{-1}$ where E_T is the total energy of the emitted set of particles. Such an event may fake the decay of a conventional heavy particle or contain pairs of heavy particles of all kinds.

The simplest configuration for the emitted particles would be a back-to-back particle - antiparticle pair, potentially able to fake possible conventional dark matter signatures.

The same situation may arise if the superbradyon decays into one or several lighter superbradyons plus a set of conventional particles, or if our physical vacuum presents properties similar to those of low-gap superconductors.

It therefore follows that data from PAMELA [14], ATIC [15], Fermi LAT [16], HESS [17] and PPB-BETS [18] can possibly be interpreted in terms of natural properties of a cosmological sea of superbradyons that are still decaying through the emission of "Cherenkov" radiation in vacuum or release conventional particles for some other reason. Whether or not data on electrons do exhibit a bump between 300 GeV and 600 GeV [21] does not change this basic conclusion.

Then, the absence of hadronic signal as well as the observed spectra of electrons and positrons can possibly be explained by specific superbradyon energy spectra, interactions and decay modes in the present Universe.

Superbradyons producing the observed electron and positron fluxes can have rest energies far above the TeV region, but this would not be necessarily the case. "Light" superbradyons with rest energies of the same order as those of the decay events or lower can also be considered. As an example, a superbradyon with $c_s \approx 10^6 c$ and $m \approx 1 \text{ eV } c^{-2}$ would have a rest energy $\approx 1 \text{ TeV}$. If its kinetic energy is of the same order, most of it can be spent in radiation in the form of "ordinary" particles. A $\approx 1 \text{ TeV}$ kinetic energy is to be compared to $m c \approx 1 \text{ eV } c^{-1}$ corresponding to a (minimal) kinetic energy $\approx 0.5 \text{ eV}$.

Another possibility would be to consider annihilations of pairs of "light" superbradyons as the possible origin of the above astrophysical data.

If such "light" superbradyons can indeed exist, producing them in an accelerator experiment would normally be excluded because of the weak couplings expected. Even in the most favorable exceptional situations, identifying such (rare) accelerator events would be far from obvious. Possibilities would exist :

- If the produced superbradyons can exhibit de-

tectable electromagnetic interactions.

- If some of them are produced in a very short-lived excited or unstable state favoring the emission of conventional particles through the "Cherenkov" effect in vacuum. Then, time of flight may allow to identify the event.

2.2. Superbradyons and gravitation

The energy of a superbradyon with inertial mass m and $v \simeq c$ would be dominated by the rest energy : $E \simeq m c_s^2 \gg m c^2$. But we do not expect its effective gravitational mass with respect to standard gravitation to be that large, as direct coupling between superbradyons and standard matter is normally assumed to be very weak. Even so, superbradyons may significantly contribute to gravitational cosmological effects, including dark energy. They can also provide [12] alternatives to the inflaton model, the transition from a purely superbradyonic universe to the present one at the Planck scale playing a fundamental role.

The possibility of a superbradyon era in the evolution of our Universe at temperatures above $\approx 10^{28} \text{ K}$ or even lower, including the Grand Unification scale, has been considered in [22]. As pointed out in this paper, this can be combined with an increasing role of deformed standard gravitation, as conventional matter is generated from the initial superbradyonic universe.

An important issue is whether remnant superbradyons are concentrated close to standard astrophysical sources. It seems difficult to answer this question.

In principle, superbradyons are expected to be weakly coupled to gravitation, and this coupling can be as weak as $\approx c_s^{-2} c^2$ times that of standard gravitation. However, as the inertial mass of a superbradyon is c_s^{-2} times its rest energy, this weak gravitational coupling can be enough to lead in practice to a strong effective reaction of superbradyonic matter to conventional gravitational fields. Then, superbradyons can strongly feel gravitation but generate very weak gravitational forces as compared to their total energy.

It is therefore not excluded that superbradyons be concentrated around the astrophysical objects usually considered in high-energy astronomy.

2.3. Other properties

Superbradyon decays, annihilations and other interactions emitting "ordinary" particles would also increase the total effective gravitational mass in our Universe. Superbradyons may even be a source of more conventional dark matter particles, including those presently considered to explain data on electron and positron abundances. They would also manifest themselves through Lorentz symmetry violation (like QDRK) in the basic physics of standard particles [12].

Even if conventional particles are assumed to be made of superbradyons, a simple calculation shows that they are in any case kinematically prevented from decaying into superbradyons, except if they are very close to rest in the VRF. Otherwise, the conventional particle would fail to provide the energy required by the total momentum. As in all cases one has $E \gg p c_s$ for a superbradyon, the "ordinary" particle should necessarily fulfill a similar requirement.

For the same reason, in a superbradyonic era of our Universe, the production of standard matter would most likely have occurred through "Cherenkov" decays and inelastic collisions rather than by direct formation of bound states.

3. Superbradyons and quantum mechanics

If matter is actually made of superluminal preons, the question of the validity of quantum mechanics for these ultimate constituents or below the fundamental length scale a should also be addressed, even if it seems very difficult to propose real experimental tests on this issue.

If the actual free superbradyons in our Universe are just quasiparticles generated from a new kind of (superbradyonic) condensed matter (the vacuum), the properties of such quasiparticles may be nontrivial. In any case, it is possible that the original fundamental superbradyons do not obey conventional quantum mechanics. Then, the usual quantum-mechanical laws would be a limit of the fundamental laws of standard matter for $p a \ll 1$ (in Planck units), while new physics would govern the region $p a \gg 1$ where superbradyons are the only "elementary" particles.

Just to give an example, a simple hypothesis on

the possible changes beyond the a scale can be a transition from the standard Planck constant \hbar to a different value of the Planck constant, similar to the change from the conventional critical speed c to the superluminal critical speed c_s . But more radical modifications can also be considered, for both space-time and quantum properties at distance scales smaller than a .

3.1. Is standard quantum mechanics a composite phenomenon ?

Can quantum mechanics be obtained from the properties of a new kind of composite medium, by combining a wave approach with topological constraints ? Are the standard gauge bosons and quantum numbers generated by topology ? Is quantization an exact property at all energies, or just a low-energy limit ?

To illustrate the idea very roughly, assume a real and positive function $f(\vec{x})$ defined on the standard three-dimensional space and such that the integral of f^2 on this space is quantified. This quantization can possibly be expressed as the limit of an energy cost for configurations.

Then, the value n of such an integral could be related to the number of composite scalar particles. Time evolution may then lead a configuration fulfilling this condition (the value of the space integral) at a time $t = 0$ towards a set of n spatially separate configurations with local f^2 integrals very close to 1, equivalent to n free particles. Otherwise, the n particles would form a bound state.

The possibility to use two complex coordinates as in [23] instead of four real space-time variables, in order to directly account for half-integer spins, also deserves consideration.

Recent and current work on the grounds and interpretation of quantum mechanics [24] may provide useful guidelines and ideas to imagine how standard particle physics can be generated from superbradyon dynamics.

Thus, standard relativity and quantum mechanics would simultaneously cease to be fundamental laws of Nature below the critical length a . This may be normal, as both principles were derived from experiments on standard matter.

Another important question deserving further

study is whether the composite origin of quantum mechanics at the Planck scale or at some other fundamental scale can lead to a detectable energy-dependent violation of quantum mechanics and to observable effects at UHECR energies.

Furthermore, if quantization can be actually the limit of the expression of an energy cost at the fundamental scale, possible tracks of non-optimal configurations should be investigated.

3.2. Are energy and momentum conserved at energies close to Planck scale ?

The validity of energy and momentum conservation above the fundamental energy and momentum scale is likely to depend on how well our description of matter can incorporate possible local vacuum inhomogeneities and similar phenomena.

For the practical purposes considered in [1,2,11], it seems reasonable to require at least energy and momentum conservation with a precision better than $\approx 10^{-4}$ eV at UHECR energies ($\approx 10^{20}$ eV) in the models used, if standard calculations are to be preserved. This is just a minimal requirement, for physics involving hadrons and nuclei as UHECR.

Patterns of energy or momentum violation should also be such that they prevent the observed UHECR from disappearing through unwanted spontaneous decays and similar processes.

Then, for instance, if the violation of energy conservation grows like E^3 , E being the energy scale (similar to the energy dependence of the deformation term in QDRK), it will remain comparatively small (less than $\approx 10^{20}$ eV) at the Planck scale ($E \approx 10^{28}$ eV). But a ($\approx 10^{-8}$ effect in the violation of energy conservation can be large enough to potentially produce important effects deserving further investigation. At the Grand Unification scale ($E \approx 10^{24}$ eV), the violation of energy conservation would be less than ≈ 100 MeV. It would become less than $\approx 10^{-28}$ eV at $E \approx 1$ TeV, and less than $\approx 10^{-37}$ eV at $E \approx 1$ GeV. It seems to follow from these figures that an experimental effect due to energy nonconservation for standard particles can only be detected at very high energy.

Questions such as vacuum structure, composition and time evolution or vacuum inner temper-

ature, should also be dealt with beyond conventional schemes in such an approach. If energy and momentum are not exactly conserved, spontaneous particle emission and absorption by vacuum, and energy nonconservation inside vacuum, also deserve consideration.

4. Conclusion

The hypothesis that the superluminal particles conjectured in our previous papers [11,12] are at the origin of electron and positron abundances considered as possible experimental signatures of dark matter, seems worth exploring irrespectively of whether or not the sources of electrons and positrons are linked to a significant component of the gravitational dark matter. Several fundamental physics issues are involved in the discussion of the superbradyon hypothesis.

Besides Lorentz symmetry violation and the actual properties of possible superluminal preons, the ideas developed here concern the origin and the interpretation [24,25] of quantum mechanics and a possible energy-dependent violation of standard quantum mechanics.

It must be noticed, however, that the explanation of the above data in terms of dark matter does not seem to be the only possible one. More conventional astrophysical interpretations have been considered in [16,26]. The question of the nature and role of dark matter has been evoked even in connection with spacecrafts and rockets [27], but associating electron and positron sources to gravitational dark matter is not a trivial step.

A detailed discussion of the basic physical questions raised in this note will be presented in a forthcoming paper.

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